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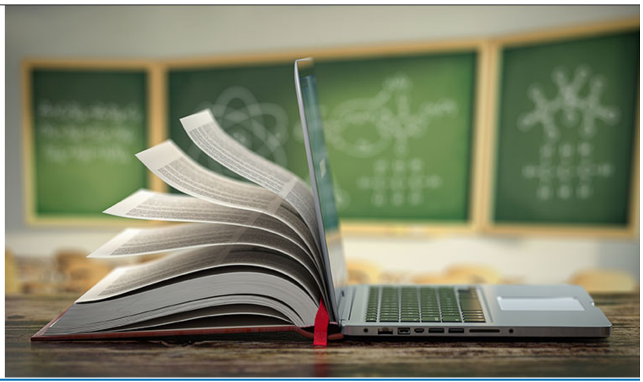

Simulation of optimal exploitation of production wells in northern oil and gas fields

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Abstract. In this paper a new model of the propagation of thermal fields in frozen soil from production wells in the northern oil and gas fields is considered. The proposed model takes into account the most significant thermal insulation characteristics of wells, including the intertube space. The developed complex of programs and the performed numerical simulatons allow to significantly reduce the area of the projected well pads of the oil and gas field by reducing the predicted radius of thawing of frozen soil from functioning wells and choosing the optimal mode of the operation during 30 years.

1. Introduction

Permafrost occupies about 25% of the entire land area of the globe. In Russia, more than 60% of the territory is related to permafrost distribution regions. The permafrost degradation processes are under influence both of climatic [1–4] and technogenic [5,6] factors. In Russia 93% of natural gas and 75% of oil are produced in permafrost regions. Human activities associated with the exploitation of northern oil and gas fields contribute to the degradation of permafrost, since various technical devices operate and affect the dynamics of changes in the permafrost boundaries [4–7]. By construction standards, producing wells cannot be drilled closer to each other than double radius of thawing during 30 years of exploitation. This means that reduction of the radius of thawing will save scarce material used to equip cluster pads, and therefore, decrease the cost of produced oil, which, given the reduction in oil prices, can be the main issue. When operating the existing northern fields, there are various options for carrying out planned technological operations related, for example, to shutting down wells, using flare systems [8, 9] for the utilization of associated gas, etc. It is an actual problem to formulate a strategy for planned activities (for example, the start time of operations, duration, schedule of well servicing) in order to reduce the value of the thawing radius.

In accordance with [4–10], modeling the processes of heat propagation in frozen soil may be reduced to solving the heat diffusivity equation with inhomogeneous coefficients, including the localized heat capacity of the phase transition in a three-dimensional domain. This approach allows solving a problem of the Stefan type without explicit allocation boundaries of the phase transition. As a nonlinear boundary condition on the soil surface, the flow balance equation is used taking into account the main climatic factors [11].

The numerical algorithm and developed software product allow predicting the long-term dynamics of temperature in the soil and the permafrost thawing. Numerical experiments have been approved for

13 oil and gas fields in Russia and the accuracy of the estimations has reached 5% in comparison with the experimental data.

The purpose of this paper is to develop a new mathematical model for the propagation of non-stationary thermal fields in frozen soil from production wells, taking into account the most significant thermal insulation characteristics of wells, including the intertube space. The developed methods and program codes for modeling thermal fields in permafrost serve to choose the most optimal options for operating production wells for a long time period of exploitation.

2. Mathematical model of heat distribution in 3D area in permafrost zones between two wells

Let $T = T(t,x,y,z)$ be soil temperature at point (x,y,z) at the time moment t. The computational domain is a three-dimensional box, where x and y axes are parallel to the ground surface and the z axis is directed downward. We assume that the size of the domain Ω is defined by positive numbers L_x, L_y, L_z: $-L_x \leq x \leq L_x$, $-L_y \leq y \leq L_y$, $-L_z \leq z \leq 0$. The main heat flux associated with climatic factors on the surface z=0 is shown in figure 1.

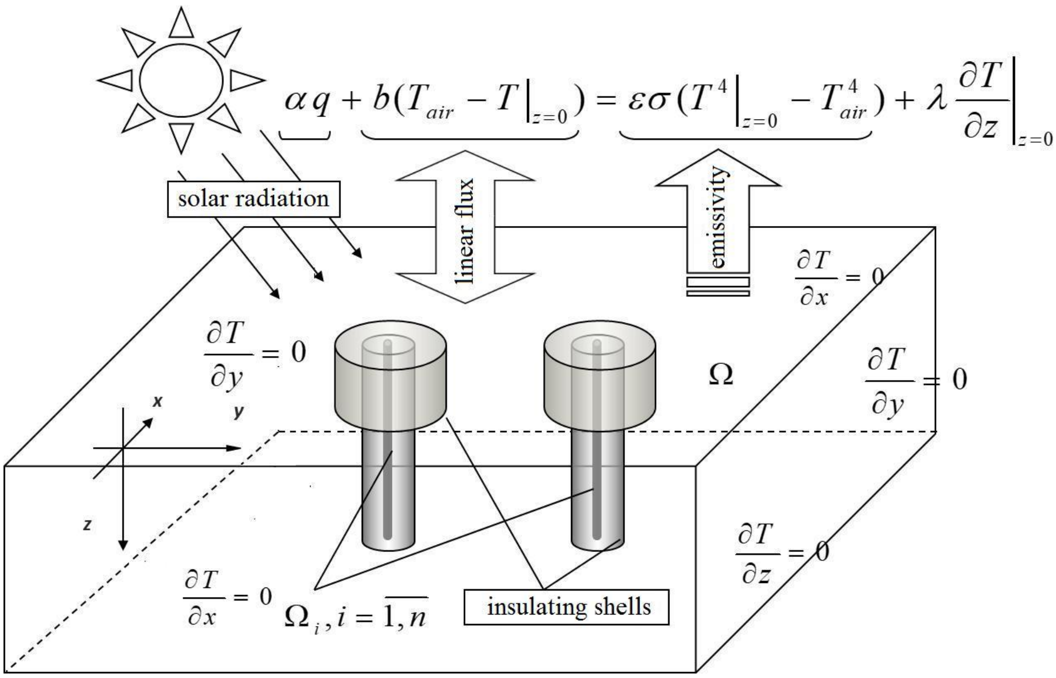

Figure 1. The main heat fluxes and boundary conditions.

Let Tair=Tair(t) denotes the temperature in the surface layer of air, which varies over time in accordance with the annual cycle of temperature; σ=5.67·10^{-8}W/(m^{2}K^4) is Stefan-Boltzmann constant; $b=b(t,x,y)$ is heat transfer coefficient; $\varepsilon=\varepsilon(t,x,y)$ is the coefficient of emissivity. The coefficients of heat transfer and emissivity depend on the type and condition of the soil surface. Total solar radiation $q(t)$ is the sum of direct solar radiation and diffuse radiation. Soil absorbes only a part of the total radiation equal to $\alpha q(t)$, where $\alpha=\alpha(t,x,y)$ is the part of energy to heat the soil, which, in general, depends on atmospheric conditions, angle of incidence of solar radiation, i.e. latitude and time. The domain Ω can include n wells. We denote the surface of these objects by $\Omega_i=\Omega_i(x,y,z)$, i=1,…,n (figure 1). In our case n=2. Following [6,7,10] the modeling of thawing in the soil is reduced to the solution in Ω of the equation

$$\rho\left(c_v(T) + k\delta(T - T^*)\right)\frac{\partial T}{\partial t} = \operatorname{div}\left(\lambda(T)\ \operatorname{grad}\ T\right) \quad (1)$$

where $\rho=\rho(x,y,z)$ is the density [kg/m^3], and $T^*=T^*(x,y,z)$ is the temperature of phase transition,

$c_v(T)=\begin{cases} c_1(x,y,z), \text{ for } T<T^* \\ c_2(x,y,z), \text{ for } T>T^* \end{cases}$ is the specific heat [J/(kg K)], $\lambda(T)=\begin{cases} \lambda_1(x,y,z), \text{ for } T<T^* \\ \lambda_2(x,y,z), \text{ for } T>T^* \end{cases}$ is the thermal conductivity [W/(m K)], $k=k(x,y,z)$ is the specific heat of phase transition, and δ is the Dirac δ-function. The ground surface $z=0$ is the main zone of formation of the natural thermal fields. On this surface the equation of balance of flows is used as a boundary condition, with taking into account the main climate factors: air temperature and solar radiation. On the surfaces Ω_i, bounding the objects in Ω, a set of temperatures $T_i(t)$, $i=1,2$ is given. On the bottom surface ($z=-L_z$) and lateral faces ($x=\pm L_x$, $y=\pm L_y$) of the parallelepiped Ω (figure 1) it is assumed that the heat flux is equal to zero.

Thus, it is necessary to solve equation (1) in the domain Ω with initial and boundary conditions

$$T(0,x,y,z)=T_0(x,y,z) \tag{2}$$

$$\alpha q + b(T_{air} - T\big|_{z=0}) = \varepsilon\sigma(T^4_{z=0} - T^4_{air}) + \lambda \left.\frac{\partial T}{\partial z}\right|_{z=0} \tag{3}$$

$$T\big|_{\Omega_i} = T_i(t), \quad i=1,\dots,n, \tag{4}$$

$$\left.\frac{\partial T}{\partial x}\right|_{x=\pm L_x} = 0, \left.\frac{\partial T}{\partial y}\right|_{y=\pm L_y} = 0, \left.\frac{\partial T}{\partial z}\right|_{z=-L_z} = 0. \tag{5}$$

An algorithm of setting the coefficient of the boundary condition (3) with taking into consideration the specific geographical location and climatic parameters of a well pad is described in [11], and the numerical approach to solving problem (1–5) based on the difference scheme [10] is described in [6, 8].

3. Numerical results

In practice, the estimation of radius of thawing from a single well is not sufficient to predict the temperature in permafrost and dynamics of permafrost boundaries. In particular, for the well allocation in a line, the interaction of the fronts of thawing generates effects of the taliks junction and the taliks roof moving. To calculate the distance between neighboring wells, it is also necessary to take into account the mutual thermal effect of these wells. In [12], this problem was indicated, and it was shown that the consideration of only the thawing radius for a single well provides lower forecast estimations. Let us simulate exploitation of double well system with a distance of 7.6 m between the wells. The computations is carried out for the following structured grid sizes: 657x347x45=8822475 nodes for a single well and 651x397x41=10596327 nodes for a double well system. Computational time of one year of life of the system takes from 70 to 140 minutes. In figures 2 and 3 the October isotherms are shown in a vertical slice $\{x,z\}$ for two continuously operating wells for 20 and 30 years. Thermophysical parameters of soils correspond to one of the northern Russian oil and gas fields. The graphs located on the right in figures 2, 3 correspond to the isotherm $T^* = -0.2$°C (phase transition temperature for the soil).

Preliminary computations for a single well estimated the radius of thawing as 1.75m for 30 years of life, and the distance between the wells is greater than the double radius of thawing. But computations for the two wells system (figure 3) show that the fronts of thawing intersect earlier than the 30 years of exploitation.

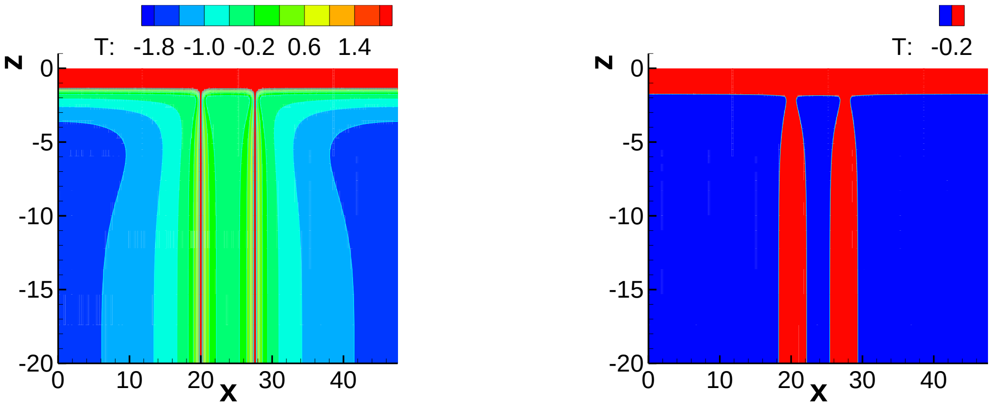

Figure 2. Thermal fields after 20 years of continuous operation of two wells at a distance of 7.6 m.

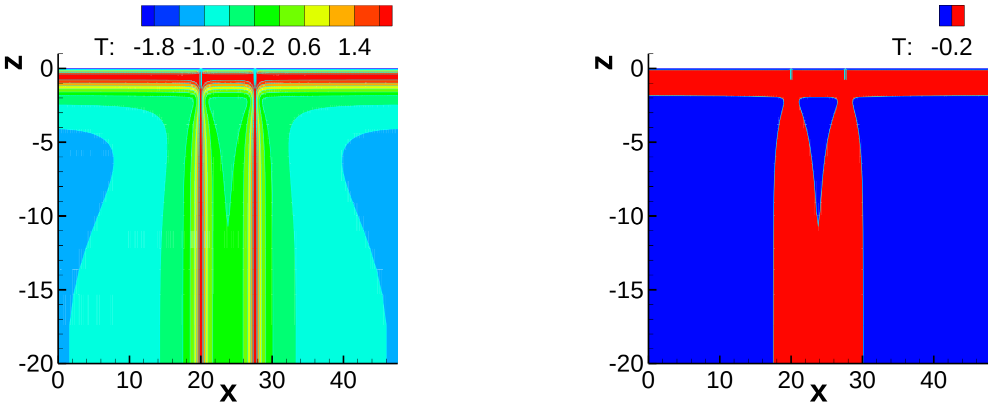

Figure 3. Thermal fields after 30 years of continuous operation of two wells at a distance of 7.6 m.

In figure 4 the thermal fields are shown for the system with periodical preventive stopping of operation for 30 days in each year of exploitation.

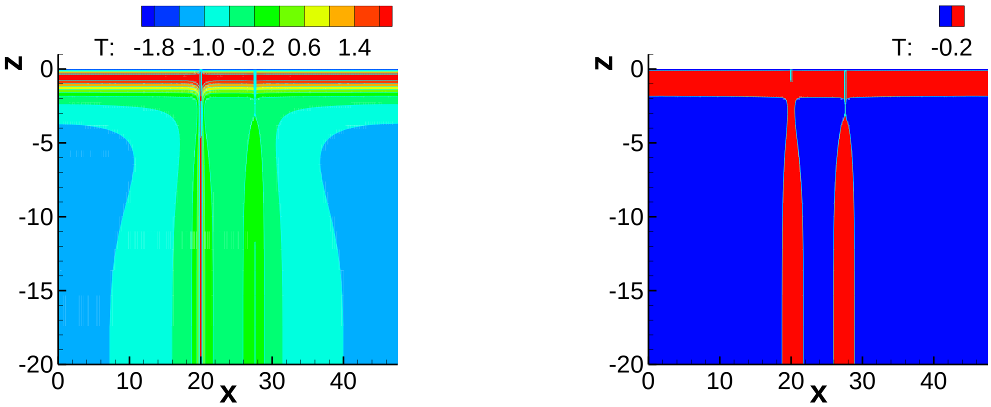

Figure 4. Thermal fields after 30 years of operation with annual preventive stopping for 30 days.

These thermal fields are close to the corresponding annual preventive stopping of each well for 14 days. In this case the temperature in the soil in the middle between the wells is -0.21°C.

It is possible to consider many other scenarios of the wells operation with the aim to avoid the taliks junction.

In figure 5 the temperature fields are shown after 30 years of exploitation and the scenario is as follows: the first 15 years of continuous operation of the wells, and then annual switching of wells (one well operates for 1 year, then it stops and another well begins to operate).

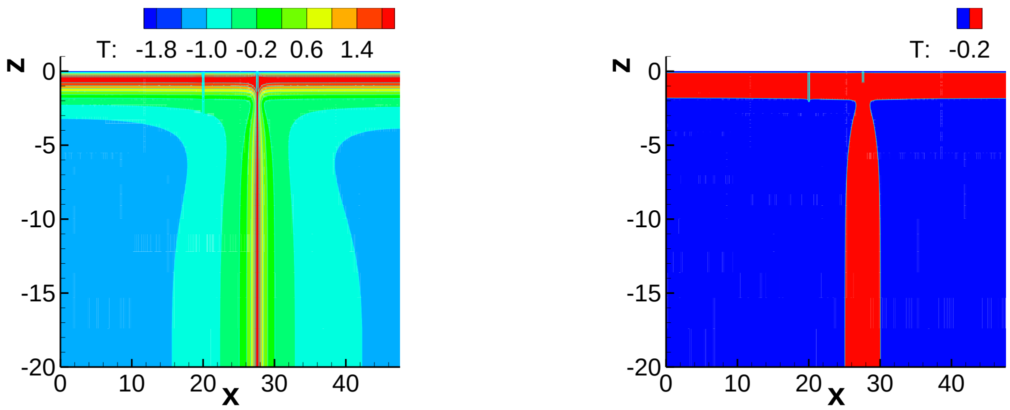

Figure 5. Thermal fields after 30 years of exploitation: the first 15 years of continuous operation of the wells, then annual switching of wells (one well operates for 1 year, then it stops and another well begins to operate).

Table 1. The soil temperature in the middle between two wells (°C).

Exploitation	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
5 years	-1.00	-1.02	-1.05	-1.00	-1.00	-1.00	-1.00
10 years	-0.66	-0.70	-0.73	-0.66	-0.66	-0.66	-0.66
15 years	-0.44	-0.47	-0.50	-0.44	-0.44	-0.44	-0.44
20 years	-0.37	-0.38	-0.40	-0.38	-0.38	-0.37	-0.37
25 years	-0.28	-0.30	-0.33	-0.35	-0.44	-0.29	-0.29
30 years	-0.18	-0.21	-0.24	-0.33	-1.09	-0.25	-0.24

In table 1 the following scenarios of the two wells system exploitation are shown:

I – 30 years of continuous operation of the wells;

II – preventive stopping for 14 days each year for each well;

III – preventive stopping for 30 days each year;

IV – 15 years of continuous operation of the wells, then annual switching of wells (one well operates for 1 year, then it stops and another well begins to operate).

V – 15 years of continuous operation of the wells, then stopping of one well;

VI – 20 years of continuous operation of the wells, then annual switching of wells (one well operates for 1 year, then it stops and another well begins to operate).

VII – 20 years of continuous operation of the wells, then stopping of one well.

Thus, all of the above scenarios of the wells operation (except I) allow allocating the wells at a distance of 7.6 m from each other for the conditions of one northern oil and gas field, but continuous operation is inappropriate in spite of the preliminary estimations of radius of thawing from a single well was good.

Conclusions
Based on the proposed mathematical model, numerical algorithms have been developed to simulate the distribution of temperature fields between production wells in northern oil and gas fields, taking into account the thermal insulation of the wells and various options for their operation. Computer simulation is carried out with adaptation to a specific oil and gas field, including the choosing of parameters included in the nonlinear boundary condition on the soil surface. Numerical experiments show that taking into account the specifics of thermal insulation of wells and the use of various options for their operation can minimize the distance between wells and significantly reduce the cost of developing a new field. In particular, scenario II (table 1) is the most common option for the safe field exploitation. Numerical simulation and application of the developed software also allow choosing various options for further field exploitation in different circumstances related, for example, to accidents in wells, or others associated with the need to reduce oil production.

Acknowledgments
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References
[1] Zhang T, Barry R G, Knowles K, Heginbottom J A and Brown J 1999 *Polar Geography* **23**(2) 132–54
[2] Zhao L, Qingbai W, Marchenko S S and Sharkhuu N 2010 *Permafrost and Periglacial Processes* **2**(2) 198–207
[3] Jorgenson M T, Romanovsky V, Harden J, Shur Y, O’Donnell J, Schuur E A G. and Kanevskiy M, 2010 *Canadian J. Forest Research* **40**(7) 1219–36
[4] Vaganova N and Filimonov M 2017 Simulation of freezing and thawing of soil in Arctic regions *IOP Conference Series: Earth and Environmental Science* **72**(1) 012005
[5] Vaganova N A and Filimonov M Yu 2015 *AIP Conference Proceedings***1690** 020016
[6] Filimonov M Yu and Vaganova N A 2015 *Lecture Notes in Computer Science* **9045** 185–92
[7] Filimonov M Yu and Vaganova N A 2016 *Journal of Physics: Conference Series* **754** 112004
[8] Filimonov M Yu and Vaganova N A 2019 *Lecture Notes in Computer Science* **11386** 233–40
[9] Filimonov M and Vaganova N 2016 *CEUR Workshop Proceedings* **1662** 253–60
[10] Samarsky A A and Vabishchevich P N 1995 *Computational Heat Transfer, Volume 2, The Finite Difference Methodology* (Chichester: Wiley)
[11] Filimonov M Yu and Vaganova N A 2018 *CEUR Workshop Proceedings* **2109** 18–24
[12] Vaganova N A and Filimonov M Yu 2014 XXXI *Siberian Thermophysical Seminar dedicated to the 100th Anniversary of academician S.S. Kutateladze. Papers of the All-Russian Conference* 42–8